ASME International

The American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017

Reprinted From
Proceedings of the 16th. International Conference on Offshore Mechanics and Arctic Engineering
Editors: Y. Ohkawa, R. C. Ertekin, T. Kinoshita, H. Maeda, K. Masuda, and K. Yoshida
Book No. H01085 - 1997

Development of an offshore type submersible platform for mariculture

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ABSTRACT

As a cooperative research project between Japan Marine Science and Technology Center "JAMSTEC" and the local government of Iwate Prefecture, the inshore type submersible platform "Marine Aya No.1" has been developed. The facility was deployed at an experimental site in December 1991 and has been tested and evaluated until now. The objective of this platform is to utilize undersea space in rias bay for maricultures, especially of abalone. As a second stage of the cooperative research between the same partner, a new offshore type submersible platform for mariculture and coastal sea was started in October 1995. The new platform was constructed and deployed at forty meters depth area in February 1996. The platform, a welded steel structure, consists of an artificial sea floor section (36.4 x 20.0 m width), a machinery room and a balance weight above and hanged beneath the floor. The artificial sea floor section submerged to seven meters depth under normal conditions and only a machinery room is afloat. The floor can be surfaced by simple operation. The major components of this platform is designed to use for five years without monitoring or checking inspection and maintenance works. The design condition is 10m and thirteen seconds of significant wave. Several research program is under examination, abalone cultivation, oceanographic monitoring, artificial reef study, measurement of movement and load to the mooring chain under rough sea condition, and so on. This platform will be one of the prospective technologies to utilize vast coastal sea area around Japan.

INTRODUCTION

The inshore area around Japan is used intensively for maricultures and their product sales amount to six billion yen a year. This is almost the same as coastal fisheries one. Main products of Japanese mariculture are yellowtail, seaweed, sea bream, pearl, scallop and oyster, in sales order. These maricultures are usually managed inshore calm sea area and almost of these area is already over used. The limit of the available depth is within ten meters from surface for suitable management of feeding operation, condition watching, cleaning of net or cages for breeding and so on.

JAMSTEC and the Iwate prefectural government had successfully developed submersible platform "Marine Aya No.1" for inshore use. The results obtained was nearly perfect in durability and as a stable platform for mariculture. The concept to utilize the middle layer of the sea for maricultures by submersible platform proved to be possible under experimental stage.[1-5]

Cooperative studies between JAMSTEC and the Iwate prefectural government was continued and started in October 1995, aiming to develop an offshore type submersible platform which can be deployed up to one hundred meters depth. New platform named "Ohcyan Marine No.1" was constructed and deployed at the experimental site in February 1996. As the platform is designed for deployment in offshore rough sea area, measuring its motions and tensions are thought to be important to develop a numerical simulation model.

In this paper, the concept of the submersible platform, development of inshore type facility, construction of offshore type facility and observation system developed for field experiments on motions and tensions will be described.

CONCEPT OF THE SUBMERSIBLE PLATFORM AND DEVELOPMENT OF INSHORE TYPE FACILITY

The submersible platform is planned to utilize vast undersea space for maricultures. Maricultures is usually managed by sea-surface-oriented devices, such as fish cultivating net fixed to floating frame, shellfish cage hanged beneath the surface raft or rope, algae cultivating rope extended at the sea level, and so on. Cultivated species which require feeding operation are to be observed for their condition almost every day and feeding is done from the sea surface. Therefore, cultivation facilities must be afloat the sea surface.

These facilities are to be located inshore where wave and current are calm. To expand these structures toward offshore, strength of facility and mooring system must be designed to bear severe conditions including frequent typhoon especially in late summer. The construction of these facilities is not so difficult when construction and operational cost are allowable, just like an oil production platform construction, of course, maricultural purposes, these costs must be reduced as low as possible.

Basic requirements of submersible platform are as follows:

a. To bear rough offshore sea condition
b. To reduce operational cost
c. Big payload
d. To reduce cost for inspection and maintenance
e. Not to use paints
f. To be deployed up to 100msw area.
g. Easy operation for users (fishermen)

To meet the requirements, possible recommendations are as follows:

a. Construct the facility by steel with cathodic protection system
b. Main component of the facility is normally submerged at the middle layer
c. Use catenary mooring system
d. Make facilities be afloat to take care of cultivated species
e. Simplify the mechanical and operation procedures for surfacing and submerging
f. Annual inspection and maintenance in main component are not necessary for five years

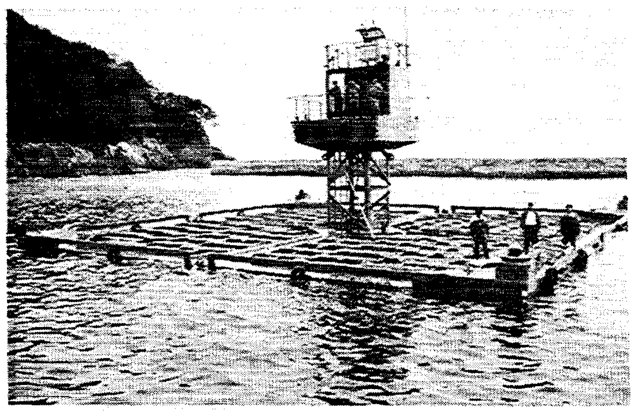

Fig.1 Inshore type submersible platform "Marine Aya No.1" at surfacing condition

As the first step to meet these conditions, inshore type submersible platform "Marine Aya No.1"had been developed and evaluated since December 1990. The platform had artificial sea floor (20 x 20m width) at four meter's depth layer, raised machinery hat to the surface at the center of it and hanged balance weight seven meters under the floor. (Fig.1). The platform can easily come up to the surface by simple operation and cheap cost. For surfacing the sea floor above sea level, diesel generator needs one liter of light oil, and it takes one hour. Submersion is done by natural flooding in fifteen minutes. It was deployed seventeen meter's depth inshore area by four point mooring. The welded steel structure was designed not to use paint and protected by aluminum cathodic protection system. Designing policy was that main component is free of maintenance and checking inspection in for five years. Cultivation of abalone has been successfully continued since May 1991. Annual experimental diving inspections (nondestructive) have been continued by authors since August 1991. The results obtained were perfect and use of middle layer for mariculture by submersible platform proved to be prospective under experimental stage. Major topics as a biological points of view are derived from the idea to cultivate abalone under their natural habitat depth layer. Many advantages were appeared by submersing, prolonged interval for feeding operation around three weeks, high alive-rate, contamination-free from river and good growth etc.

OFFSHORE TYPE SUBMERSIBLE PLATFORM

Submersible platform for offshore use was designed by using many useful data which were obtained by the experimental evaluation of the inshore type facility "Marine Aya No.1". Basic concept is almost the same as the inshore type, except that the size is larger as shown in Fig.1. The facility was named "Ohcyan Marine No.1" and was deployed at forty meters depth area in Funakoshi bay on 17th November, 1996. (Fig's 2-5).

OUTLINE OF THE FACILITY

General arrangement of the submersible platform is shown in Fig.6. The facility is a welded steel structure composed of an artificial sea floor ($33.6m^L$ x $20m^B$, $666m^2$ area) and an operational machinery room supported by four columns, and is anchored to the sea floor at two point with loose catenary chain cables. The artificial sea floor surface is normally submerged in the layer of about 7m below the sea surface, and can be afloat by discharging sea water from a center tank. Abalones are cultivated in breeding baskets which are fastened to the steel frames on the artificial sea surface. The baskets are in such position that their upper parts are above the sea surface when the facility is afloat.

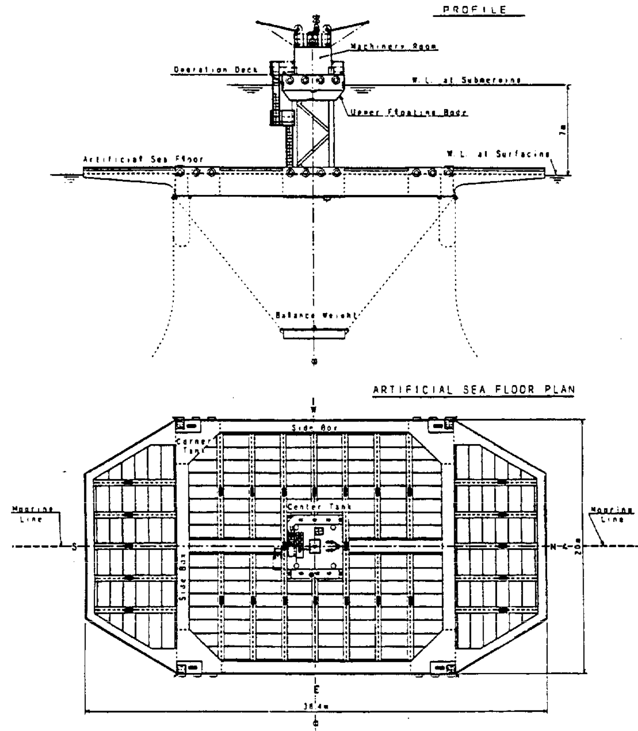

Fig.2 General arrangement (plan & profile) of offshore type submersible platform "Ohcyan Marine No.1"

Principle particular's

Length of the artificial sea floor	36.4 m
Breadth of the artificial sea floor	20.0 m
Position of the artificial sea floor surface	
Submerging condition	6.9 m below the sea surface
Surfacing condition	0.1 m above the sea surface
Draft adjustment capability	20 t
Time required for surfacing	60 min
Time required for submersing	25 min

Design condition

Wave : Significant wave height	10.0 m
Significant wave period	13.0 sec
Current velocity	1.0 m/sec
Wind velocity (Mean)	40.0 m/sec

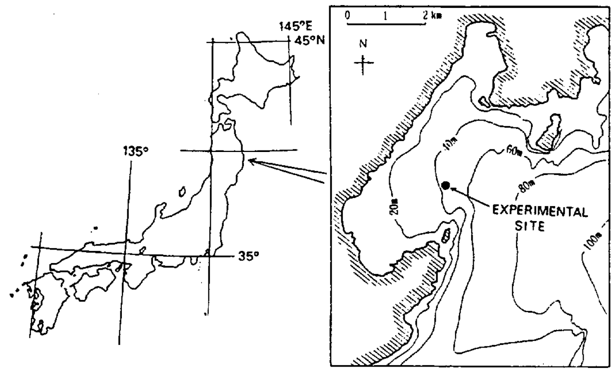

Fig.3 Location of experimental site

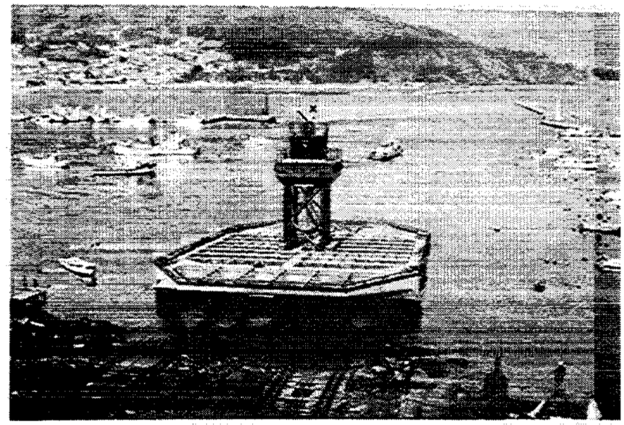

Fig.4 Launching of "Ohcyan Marine No.1"

FACILITY CONSTRUCTION

Artificial sea floor section

Main component of the submersible platform is an artificial sea floor, which is composed of a flat shelf of framework and five tanks as shown in shown in Fig.6. The surface of the artificial sea floor is composed of beams at 1m pitch fitted on the girders. Beams are used to support baskets for abalone breeding and FRP gratings for access. Four corner tanks are connected by box structures (side boxes) in square. One center tank and the side box of periphery are connected by longitudinal and transverse girders. Both wing parts are of overhang structure.

The center tank governs submerging and surfacing of the facility. Surface of an artificial sea floor is switched between the submerged position in the layer of about 7 m depth and the surfaced one, about 10 cm above the sea surface. Four corner tanks govern draft and attitude adjustment. When the facility is built and placed at the site, four tanks are filled with sea water. Even when any unbalanced load occurs due to cultivation equipment, marine growth, etc., the draft and attitude of the facility can be adjusted easily by discharging the water in these tanks.

Superstructure

The superstructure is supported by four columns standing on the deck of the center tank to be kept above the sea surface during submerging. The supporting structure of the superstructure is designed to have a least buoyancy to reduce the ballast water for surfacing and submerging operation. Upper floating

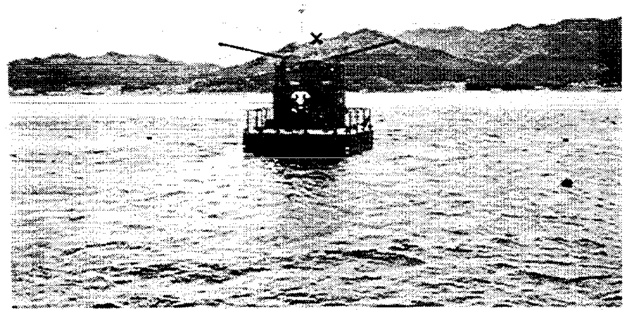

Fig.5 Submerged condition (normal) of "Ohcyan Marine No.1"

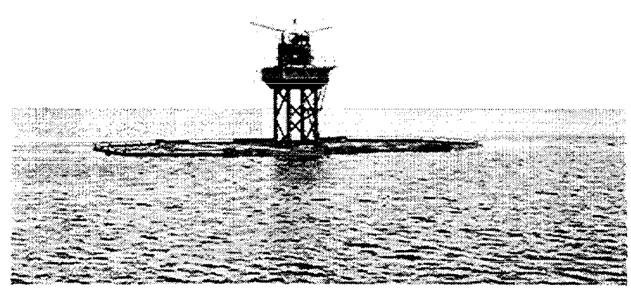

Fig.6 Surfacing condition of "Ohcyan Marine No.1"

The water pumps (120/240 L/min x 10/7 mTH, 750 W) are installed at the bottom of the center tank to discharge ballast water. Discharging pipes are once raised through the tank top wall and provided with a gate vale each. They are connected to one discharging pipe that has an air vent pipe on it's top. The air pipe prevents the sea water from reversing due to siphonage in the afloat condition. The gate valve is shut at the time of the pump not working to prevent the sea water from reversing by the other pump. A float switch is provided above the center tank bottom so that the pumps can stop automatically.

OPERATION PROCEDURE

Submerging/surfacing procedures of the facility are very simple. For surfacing, the operator starts the diesel generator, and then two discharging water pumps. About one hour later, the pumps stop automatically. Then he stops the generator. For submerging, he opens the double flooding valves. The facility complete submersing through natural flooding in about 25 minutes. The above operation can be carried out by one man easily and safely.

MOTIONS AND TENSIONS OBSERVATION OF THE SUBMERSIBLE PLATFORM

An observation system was developed for field experiments on motions and tensions of a submersible platform.

OBSERVATION SYSTEM

Figure 10 shows a conceptual view of the observation system. A machinery room is located on the main deck to store the electrical and machinery systems, and on the roof top of the cabin a wind gauge for measuring wind velocity and direction is fixed at a height of 6 m above the water surface: this height is slightly lower than the standard measurement, which is usually 10 m from the surface. If wind data for meteorological study is needed, the data can be transformed to the value at 10 m. At this stage we use it to grasp the sea conditions of where the structure placed.

A magnetic azimuth and a solar battery panel are also set on the rooftop; the azimuth was confirmed not to be effected by the circumstance metal. The solar battery panel can supply 6 watts under standard weather conditions, which is adequate for our measurement system that consumes 5.5 watts. The solar battery system is backed up by a chemical battery system, which, under fully charged condition, can supply the electric power for 1/2 month without a charge from the solar battery.

Two type capacity of wave height sensors are fixed between the boom and the submerged floor as shown in Fig.10. To measure incident waves, the sensors should be apart from the structure itself to avoid any effect, but the phase difference between the incident wave and motions of the structure is important in the study of the dynamics of the floating structure. The floating structure is moored parallel to the coastline and the two wave height sensors are not sheltered by the structure, therefore the effects are not serious.

Waterproofed tension gauges are put on mooring lines directly at the top end of mooring lines. The effect of temperature variation on the strain measured with these gauges can be canceled by using two tension gauges and two dummy gauges.

In the machinery room, a motion sensor composed of three accelerometers and three piezoelectric oscillator type gyroscopes measures 6-degree freedom motions of the floating structure. A piezoelectric oscillator gyroscope measures angular velocity around its axis without an effect of acceleration, because this effect is canceled by using the two oscillators output, i.e.,: the angle of space fixed coordinate can be decided by integrating and transforming the angular velocity inside the motion sensor. The acceleration about the body fixed coordinate is transformed into the space fixed coordinate inside the motion sensor, and the displacement of the floating structure is obtained by integrating the acceleration. To avoid the effects of noise and error, a band pass filter (1/15 HZ~3HZ) was applied to the data. The moored floating structure oscillates at low frequency by the action of wind, current and nonlinear wave forces and the low frequency component motions contained in the observed data might be significant regrettably, due to the lack of accuracy of the motion sensors, we cannot discuss this problem.

body is filled with buoyant material so that the buoyancy can be secured even when the structure is damaged. Operation deck.is prepared around the machinery room. Arrangement of the room is shown in Fig.7. Installed inside the room are a diesel generator (6 KVA, 9 Ps) and two operation stands for water charging valve, a water discharging pump operation board, etc.for the center tank ballasting system.

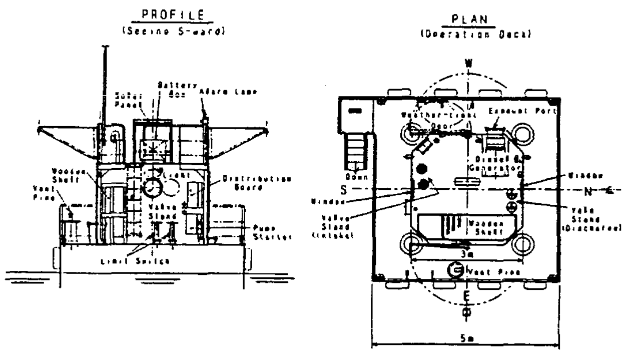

Fig.7 Arrangement of Machinery Room (plan & profile)

Balance Weight

To improve the stability during surfacing/submerging, and considering that, many people are at work on the artificial sea floor in afloat condition, a balance weight of about 30 tons in underwater weight is hung beneath the sea floor structure. The balance weight is a steel box filled with concrete and is connected to each outside the four corner tanks with chain cables.

Mooring System

This facility is loosely moored with two chain cables. Since the coming wave direction is east, two mooring lines are developed in the north-south direction so that the facility motion by wave may be free, as shown in Fig.8.

The mooring line is composed as follows:

9-ton danforth anchor + 44 mm dia, (Gr3) chains x 130m + 98 mm dia. (Gr2) chain x 45 m + 42 m dia. (Gr3) chain x 22m + 52 mm dia. (Gr3) chains x 3m / [reserve] 42mm dia. (Gr3) chain x 5m

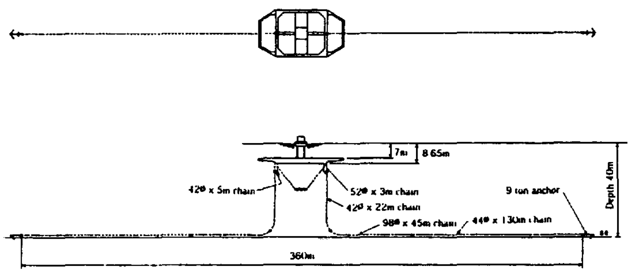

Fig.8 Mooring System Layout (plan & profile)

Cathodic Protection System

Aluminum alloy anodes are fitted on the underwater part of the facility. The designed life of the anodes is 5-year.

Ballasting system

Piping diagram of the ballasting system is shown in Fig.9. The flooding line for the center tank is connected to a sea water intake of the pipe vertically through the center tank of which the top and bottom are open. The other end of the line is opened at inside the center tank via two gate valves. Since these valves are to be shut from the sea directly, double valves are arranged in series to secure the water tightness in the closed position, and the machinery room. To fill the center tank with seawater full by natural flooding even during the facility surfacing, a well is provided at the top of the tank and a flooding line is led under the waterline in the afloat condition.

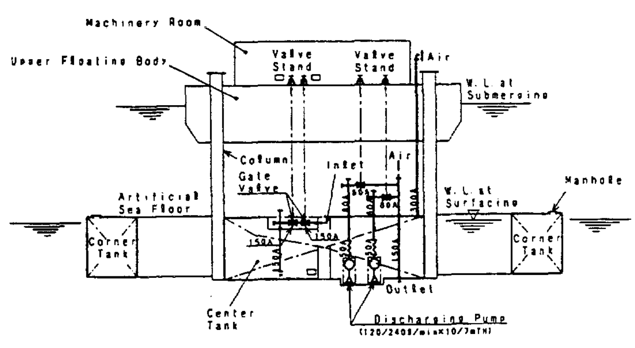

Fig.9 Piping diagram of the ballasting system

FIELD OBSERVATION

The first field experiments to measure the motions of the floating structure were carried out in February 1996. Figure 11 shows an example of the data recorded then. From the top left the time series shows wind direction and wind velocity, incident wave height which is the average of the data obtained with two wave height sensors and therefore the effects of rolling is compensated; surge, sway, heave, from the top right, roll, pitch, yaw and tensions of two mooring chains. Measuring was carried out every two hours, for 15 minute each time. The sampling time was 3Hz.

The figure shows that the wind direction was stable around 80 degree that means the east wind. The mean value of the wind velocity is 5m/sec and the amplitude of the fluctuation is about 2 m/sec: this have induced the sway motion. The period of the tension variation coincides to those of the wind and sway motion. The object floating structure is a kind of semi-submersible and the wave forces acting on the structure is small. The figure shows that the wind is important for estimating the mooring tension.

Records of the two wave height sensors were very similar to each other and the average value will be used for analyzing the motions of the structure to compensate the effects of pitch and roll. The relative wave height measured by the wave height sensors was corrected to an absolute wave height by adding the record of the heave of the structure to that of the wave height. The record shows that the incident waves were composed of the swell and wind waves, and the motions were mainly induced by the swell. The structure is moored near the coast and the wave generated by the seasonal northwest wind is not so big but the swell comes from the east-south that is the direction of the open sea and the direction of the swell and wind wave might be opposite. We should be careful about this when we carried out the numerical simulation for the motions and tensions.

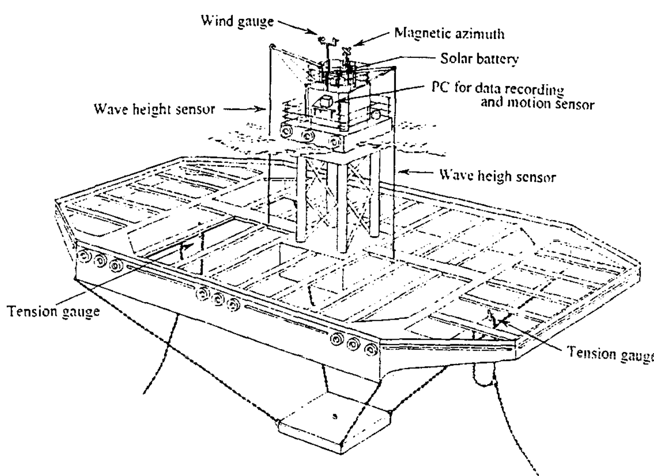

Fig.10 Conceptual view of setup of field experiment

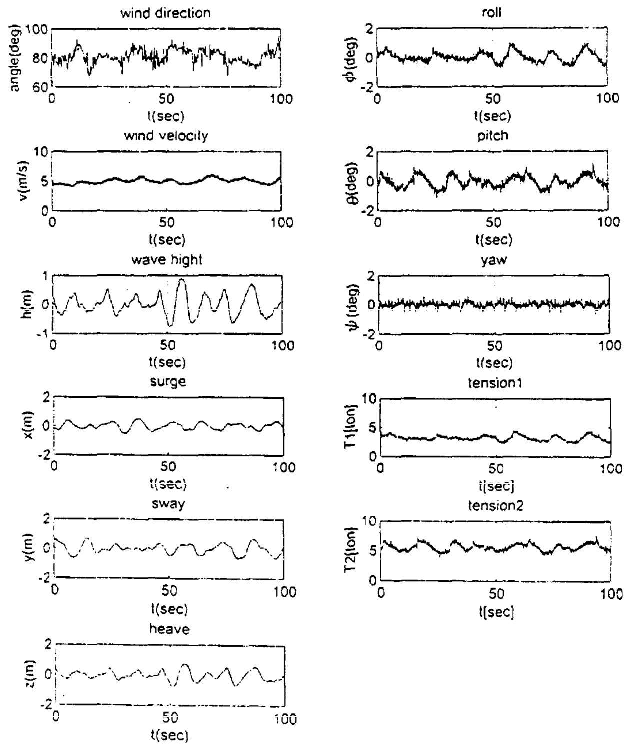

Fig.11 Example records of field experiment

CONCLUSION

It is a new challenge to use vast undersea space for maricultures by submersible platform. Inshore type facility "Marine Aya No.1" has been successfully under operation since December 1991 and offshore type "Ohcyan Marine No.1" started experimental evaluation since February 1996. Research themes for the offshore type facility is not limited in abalone mariculture but also artificial reef study and oceanographic survey to use it as a marine observation station. As to the facility itself, surveying durability of the facility, development of maintenance and inspection technology for emergency are major interest. All these themes are nearly the same as examined by inshore type facility.

Width of coastal sea area within one hundred meters depth around Japan is 160,000km^2 that correspond to forty-two percent of the width of Japan. For the use of the offshore type facility around these areas, it is important to develop a standard of the facility's design to adapt different environmental conditions. Designing a floating offshore structure requires theoretical and experimental studies to decide the anticipated performance and safety. In the final stage of the design, the performance under a working condition and the safety under the survival condition should be confirmed by numerical simulation programs developed from these studies.

Establishment of a numerical simulation method reflecting the dynamics of a submersible platform is necessary; yet the difficulties confronted are much more serious than the case of large oil rig: the incident wave height is relatively large in comparison with the scale of the floating structure, which leads to strong nonlinear effects. For an oil rig, the nonlinear effect is small enough to be neglected except the phenomenon of so called slow drift oscillation. The computer program developed for the numerical simulation of motions of a small structure must therefore be validated by experiments as it was done by many researchers over the past twenty years for a large offshore structures. For shallow water or coastal mooring, there is another difficulty that the waves themselves are nonlinear due to the shallow water effect or breaking wave phenomena; in addition, the mooring lines are too short to absorb the motions of the floating structure induced by waves, and they suffer from snap loads in a severe sea state and this makes the study on the nonlinear dynamics essential for this condition.

Whole research program regarding the offshore type submersible platform are under examination now. Those results will be presented in another opportunities.

ACKNOWLEDGEMENT

The authors wish to acknowledge the efforts of many persons from the Department of Planning and Coordination and the Department of Forestry's and Fisheries, Iwate Prefectural Government, Outsuchi Fisheries Cooperative Association and Japan Marine Science and Technology Center, who made the second challenge to develop "Ohcyan Marine No.1" possible.

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